SPACE TUG

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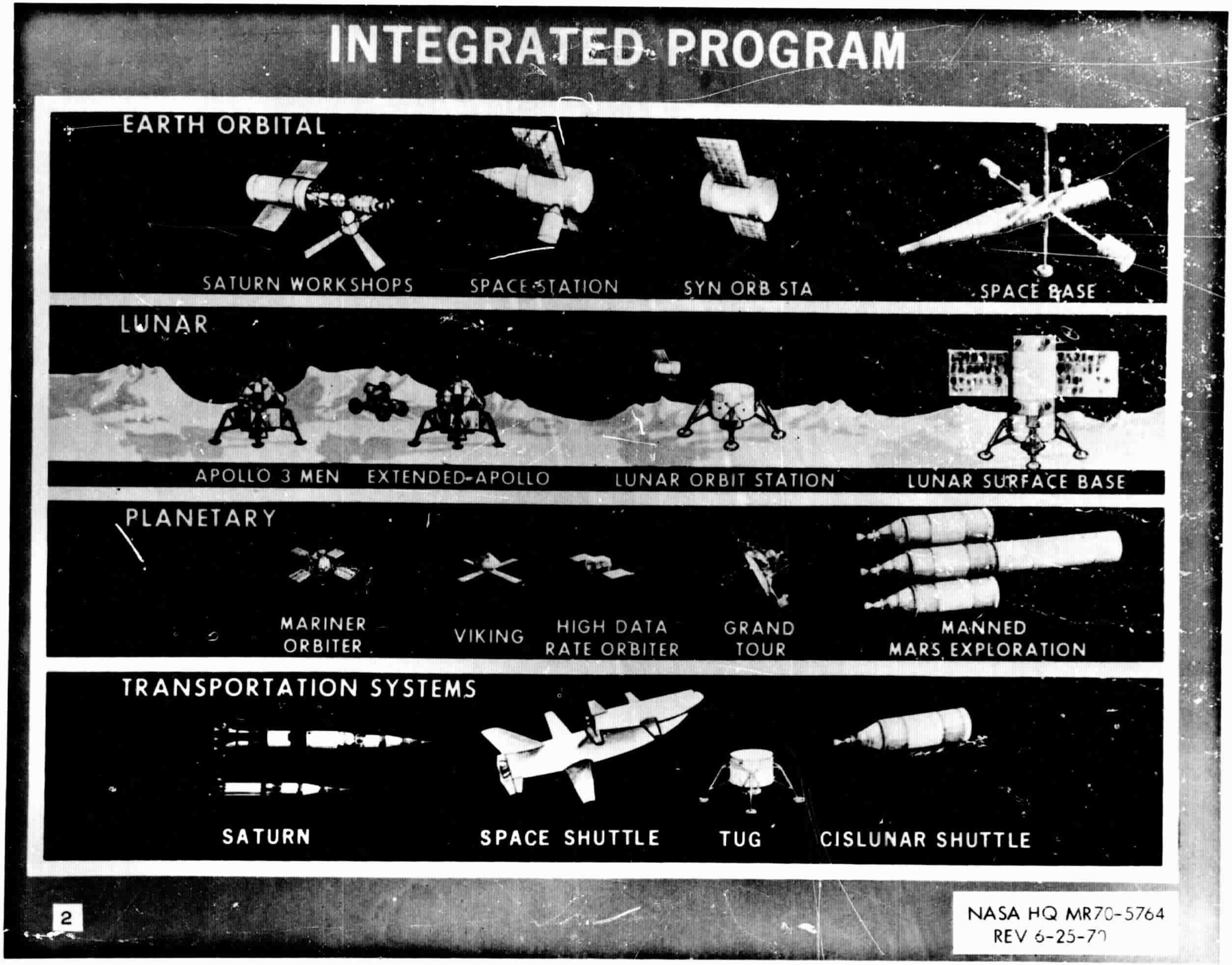
PRESENTATION

ELDO/NASA
SPACE TRANSPORTATION SYSTEM BRIEFINGS

BONN, GERMANY

JULY 7-8, 1970


INTEGRATED PROGRAM
EARTH ORBITAL
SATURN WORKSHOPS
SPACE STATION
SYN ORB STA
SPACE BASE
LUNAR
APOLLO 3 MEN
EXTENDED APOLLO
LUNAR ORBIT STATION
LUNAR SURFACE BASE
PLANETARY
MARINER ORBITER
VIKING
HIGH DATA RATE ORBITER
GRAND TOUR
MANNED MARS EXPLORATION
TRANSPORTATION SYSTEMS
SATURN
SPACE SHUTTLE
TUG
CISLUNAR SHUTTLE
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INTEGRATED PROGRAM

An overall plan for space exploration and utilization has been established. This program plan is flexible. No specific time schedule is placed on the longer term elements. The plan builds toward establishment of permanent bases - first in earth orbit then extending out into deeper space with a system of reusable transportation systems for logistic support. Usually the larger manned systems are preceded by smaller unmanned systems. But ultimately the features of both are incorporated in the future space activities.

DEFINITIONS

SPACE SHUTTLE	REUSABLE ROUND TRIP EARTH TO ORBIT PRIMARY TRANSPORTATION VEHICLE.
SPACE TUG	REUSABLE MULTIAPPLICATION ORBIT TO ORBIT TRANSPORTATION VEHICLE. TRANSPORTED TO AND FROM EARTH ORBIT BY SPACE SHUTTLE AND TO AND FROM LUNAR ORBIT BY THE CISLUNAR SHUTTLE. TUG ALSO USED FOR TRANSPORTATION FROM LUNAR ORBIT TO LUNAR SURFACE AND RETURN.
CISLUNAR SHUTTLE	RESUABLE TRANSPORTATION VEHICLE FOR LARGE PAYLOADS BETWEEN EARTH ORBIT AND LUNAR ORBIT.

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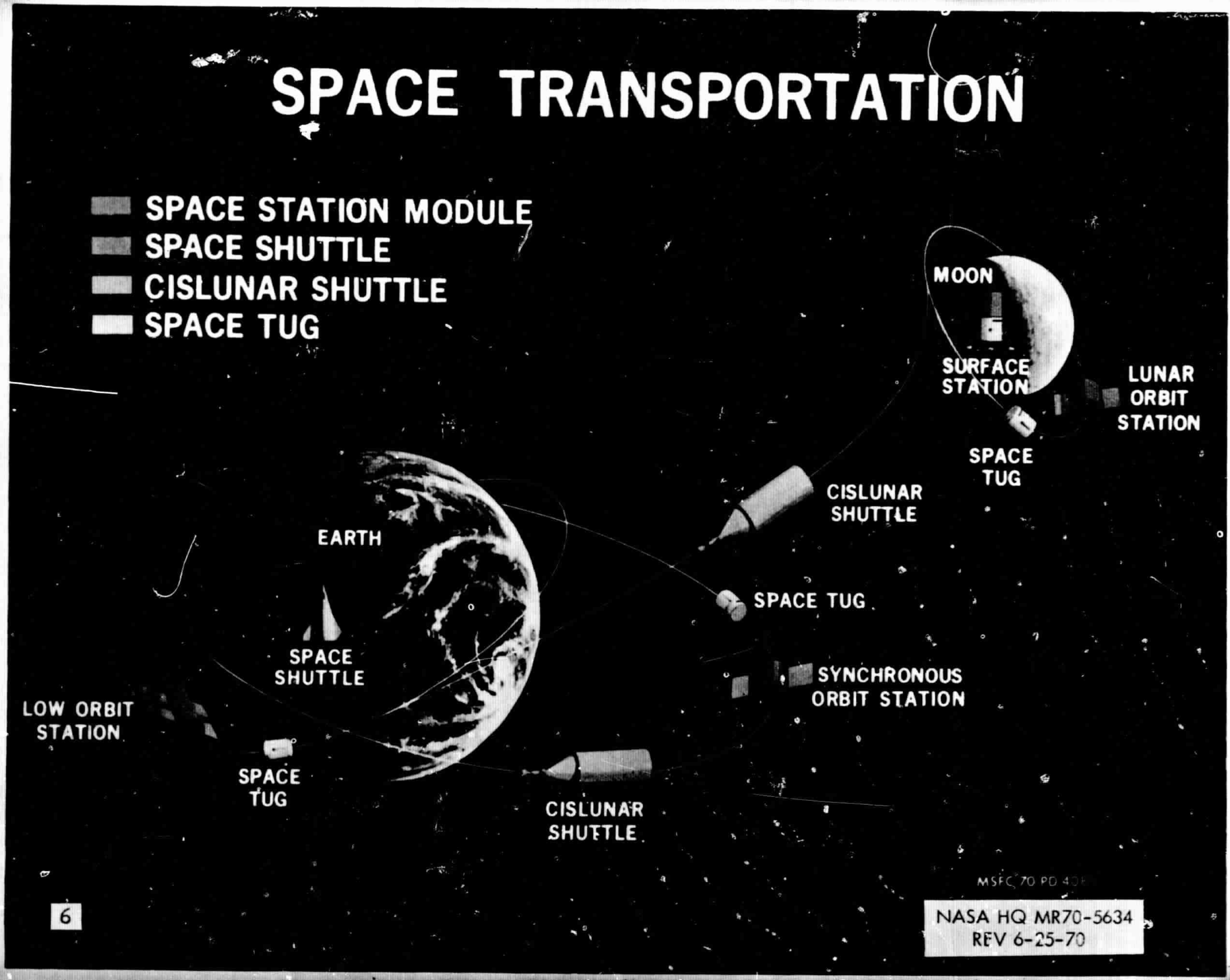
DEFINITIONS

To avoid confusion in terminology in subsequent charts, a brief definition of the Space Shuttle, often called the Earth Orbital Shuttle (EOS), the Space Tug and the Cislunar Shuttle are given here.


SPACE TRANSPORTATION
SPACE STATION MODULE
SPACE SHUTTLE
CISLUNAR SHUTTLE
SPACE TUG
MOON
SURFACE STATION
LUNAR ORBIT STATION
SPACE TUG
CISLUNAR SHUTTLE
EARTH
SPACE TUG
SPACE SHUTTLE
SYNCHRONOUS ORBIT STATION
LOW ORBIT STATION
SPACE TUG
CISLUNAR SHUTTLE
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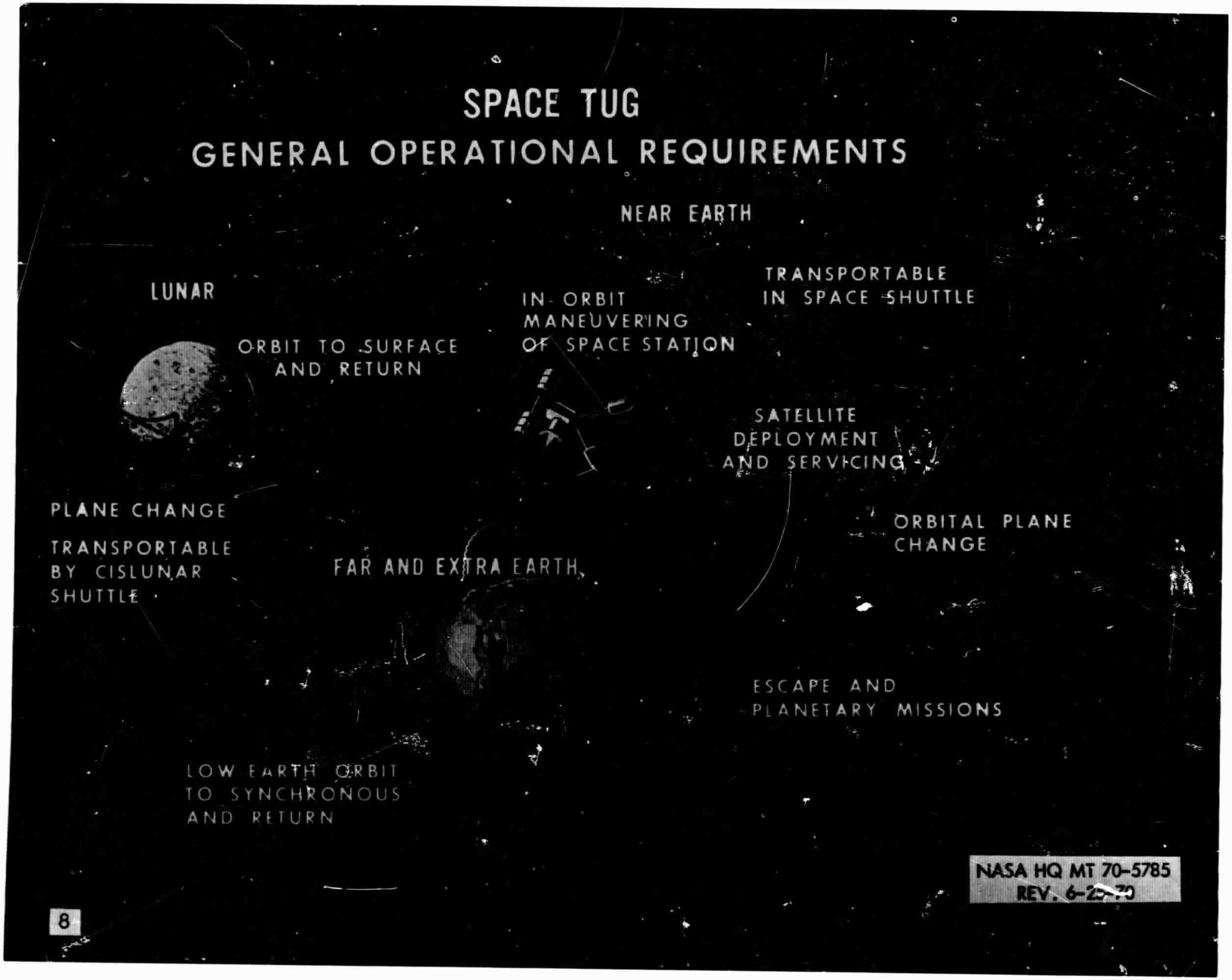
SPACE TRANSPORTATION

This illustration includes the major elements of the space transportation system as it is now envisioned. A key feature of this system is that all of its elements, the Space Tug; the Space Shuttle; and the Cislunar Shuttle will all be designed for a maximum degree of mutual operational compatibility and flexibility. For example, the Space Shuttle will be able to deliver the Space Tug to earth orbit and then service it. The Space Shuttle will also carry propellants, payloads, and other operational logistics for the Cislunar Shuttle. The Cislunar Shuttle will be able to transport the Space Tug for operations in deep space.

As space exploration moves into the future development of the Space Base, extended lunar missions and manned planetary expeditions, the space transportation system elements pictured here will be key program components.


SPACE TUG
GENERAL OPERATIONAL REQUIREMENTS
NEAR EARTH
LUNAR
ORBIT TO SURFACE AND RETURN
IN-ORBIT MANEUVERING OF SPACE STATION
TRANSPORTABLE IN SPACE SHUTTLE
SATELLITE DEPLOYMENT AND SERVICING
PLANE CHANGE
TRANSPORTABLE BY CISLUNAR SHUTTLE
FAR AND EXTRA EARTH
ORBITAL PLANE CHANGE
ESCAPE AND PLANETARY MISSIONS
LOW EARTH ORBIT TO SYNCHRONOUS AND RETURN
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SPACE TUG

GENERAL OPERATIONAL REQUIREMENTS

The variety of missions and operational requirements that have been projected for the Space Tug are illustrated in this sketch.

Earth Orbital potential missions include:

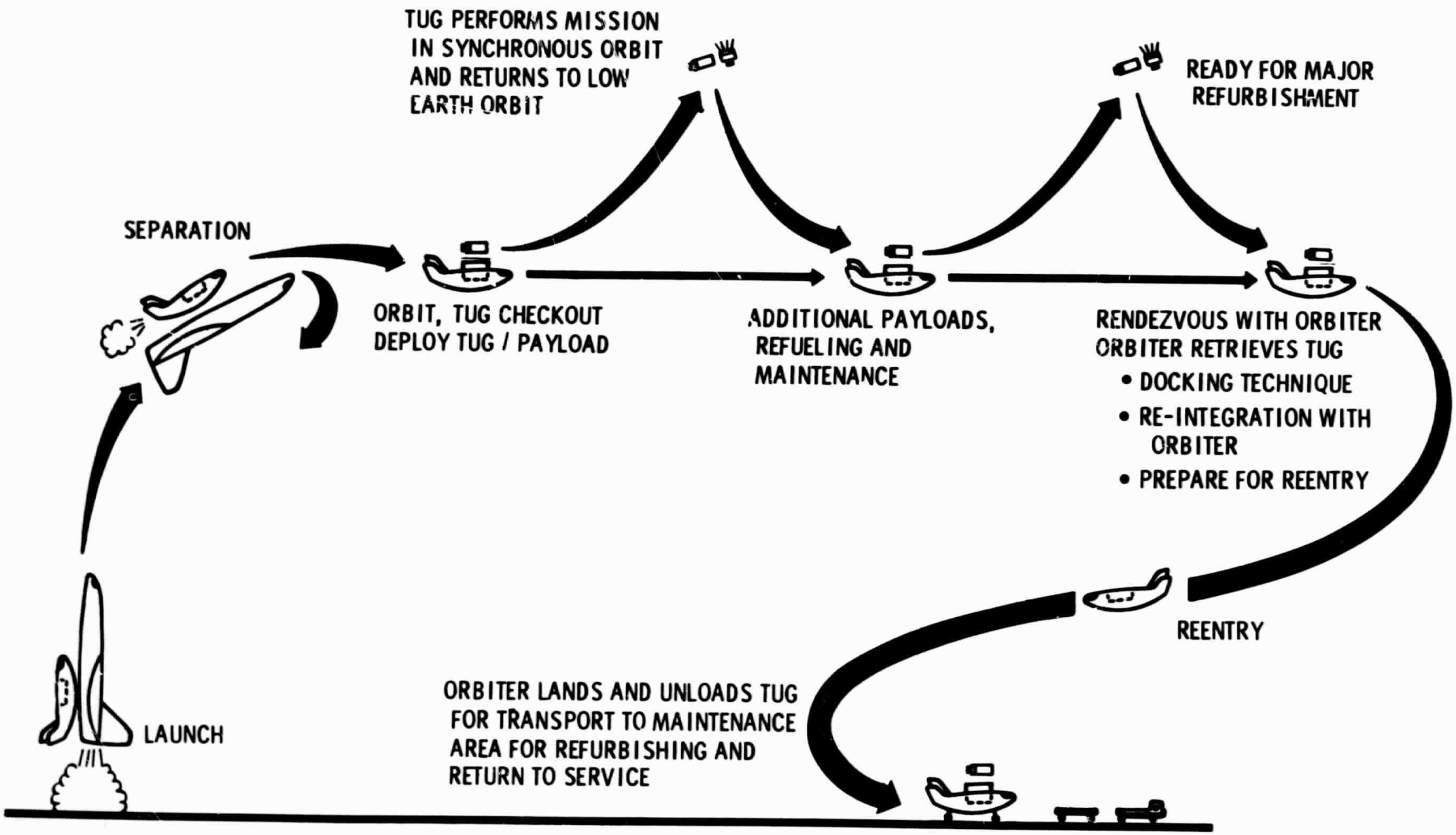
a. Space Station/Base support activities such as transfer of payloads from the Space Shuttle, orbit keeping, Space Base assembly and maintenance support.
b. Orbital service station - propellants, hangar, checkout and maintenance, assembly.
c. Satellite placement and retrieval (low to high energy orbits).
d. On-orbit satellite servicing and inspection.
e. Satellite and unmanned interplanetary spacecraft launch.
f. Crew shuttle to high energy orbits and crew rescue.

Potential Lunar mission examples are:

a. Lunar orbit to surface to orbit crew transfer.
b. Delivery of lunar surface payloads.
c. Rescue.
d. Earth orbit to lunar orbit (small payloads)

The Tug is transportable from earth surface to earth orbit by the Space Shuttle and from earth orbit to lunar orbit by the Cislunar Shuttle.

SPACE TUG BASELINE OPERATIONAL CYCLE



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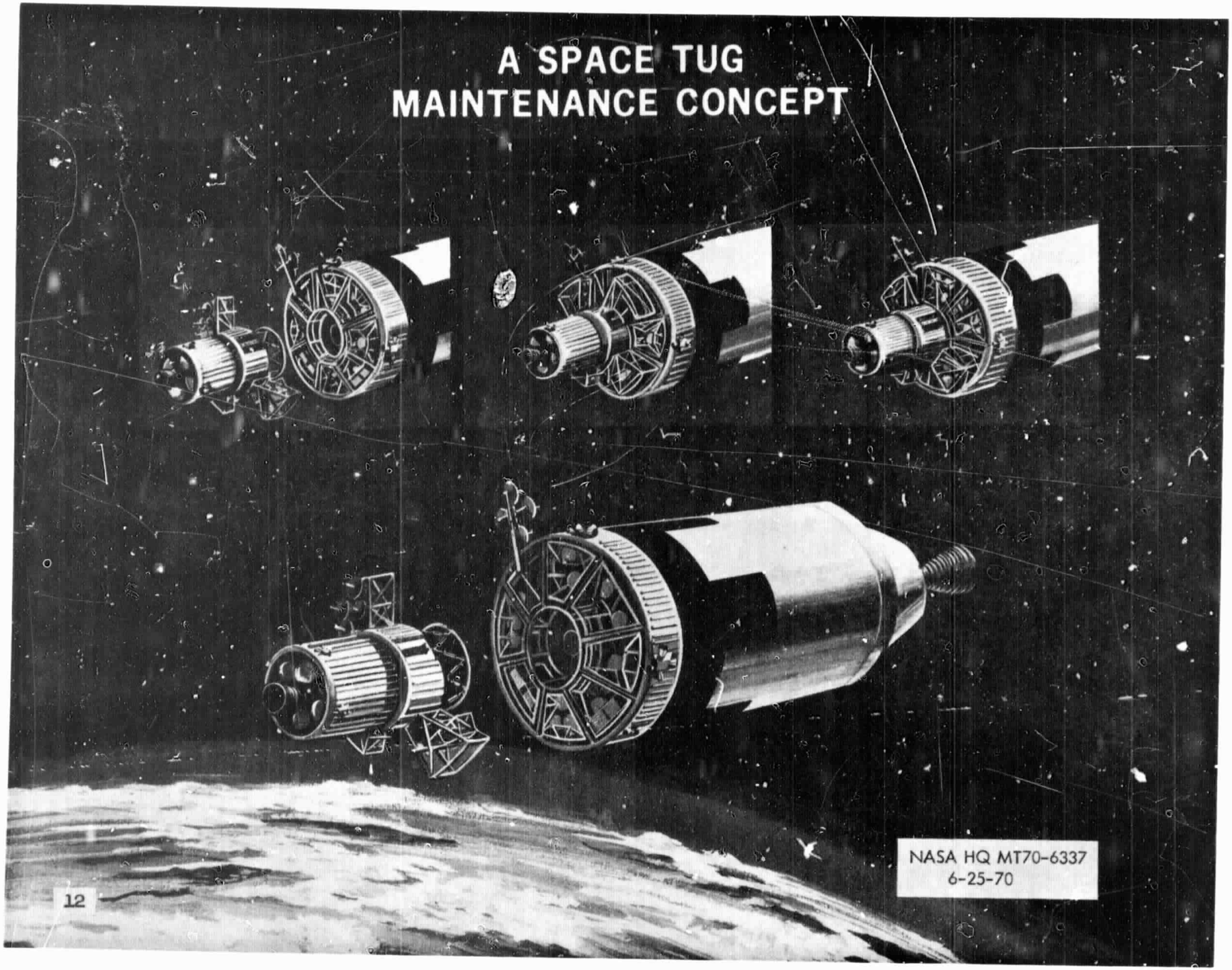
SPACE TUG BASELINE OPERATIONAL CYCLE

The Tug is delivered to orbit by the Space Shuttle. After performing its mission and returning to low earth orbit the Tug can receive additional payloads, fuel and necessary servicing in orbit to perform repeated missions (space basing concept). Eventually the Tug would be returned to earth for major refurbishment. For missions involving a very large payload or requiring very high ΔV the Tug could be expended.


A SPACE TUG
MAINTENANCE CONCEPT
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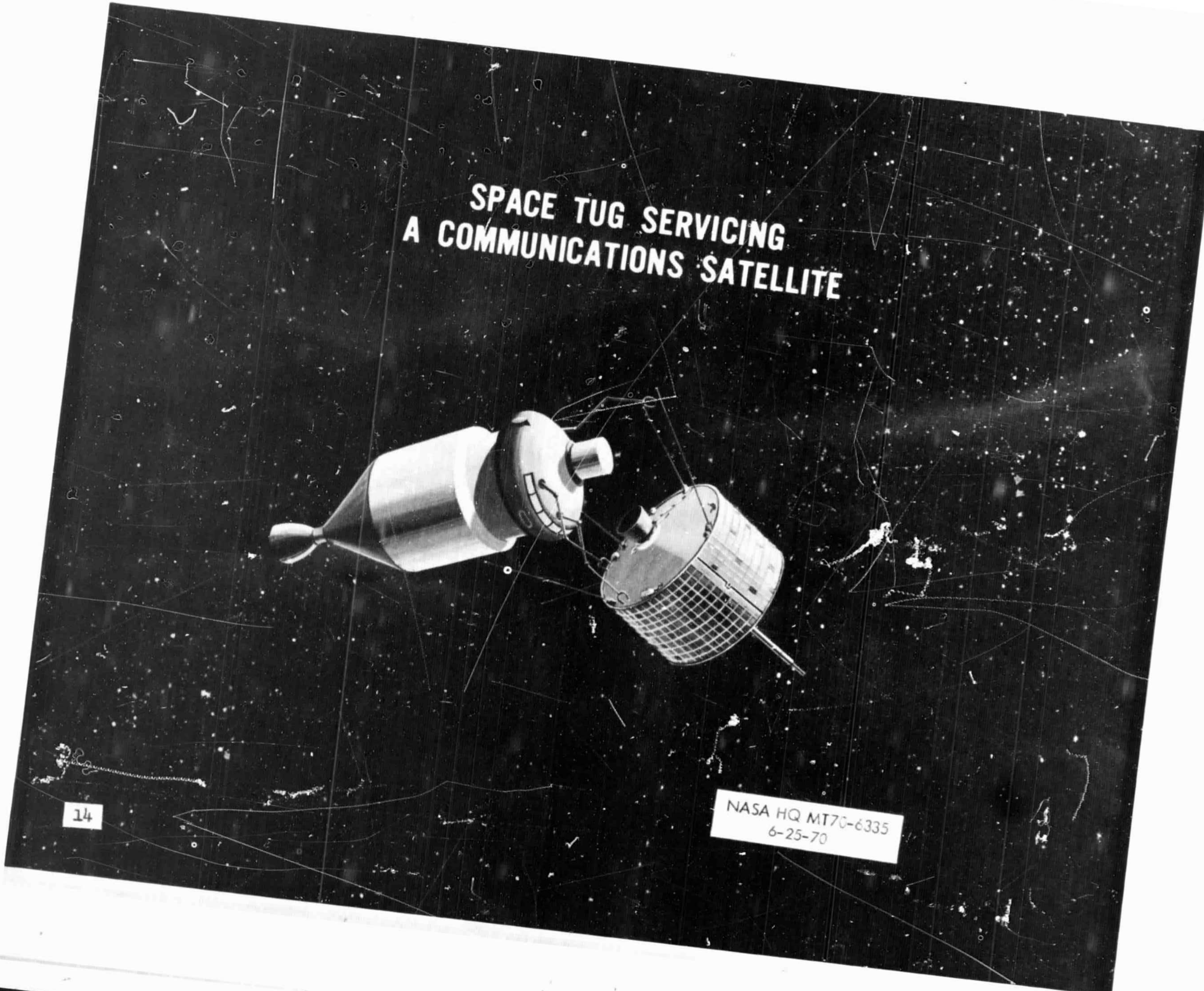
A SPACE TUG MAINTENANCE CONCEPT

The overall view shows a Cislunar Shuttle being approached by an unmanned maintenance Tug. The Tug has three replacement modules attached to a turntable assembly. The first view shows an expanded section of the Cislunar Shuttle with the Tug approaching. The three replacement modules are in position on the turntable assembly. The Tug will be docked with the Cislunar Shuttle using a standard docking mechanism. The second small view shows the Tug harddocked to the Cislunar Shuttle. A module is being removed from the Shuttle. The third small view shows the turntable rotated and a module being installed in the Cislunar Shuttle. After the maintenance operation is completed the two vehicles are demated and the Tug backed off as depicted in the lower illustration.


SPACE TUG SERVICING
A COMMUNICATIONS SATELLITE
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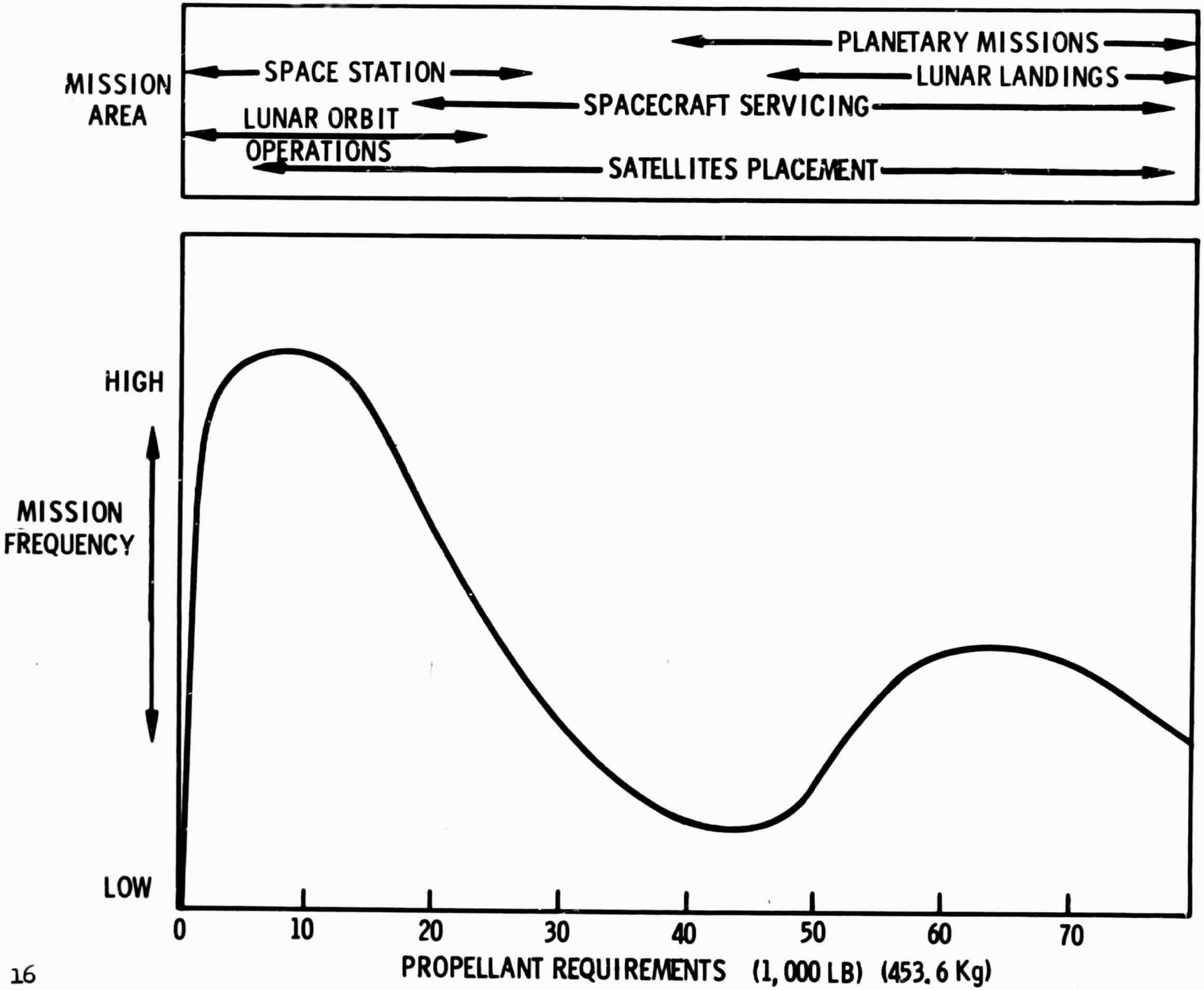
SPACE TUG SERVICING A COMMUNICATIONS SATELLITE

Shown here is an artist's concept of a manned Space Tug servicing a communications satellite. Servicing of satellites will be economical and desirable in many cases in the future. However, the satellites will have to be designed to permit servicing. Existing satellite systems which are designed without consideration of inspace maintenance probably could not be effectively serviced even by a highly sophisticated satellite maintenance/repair kit used in conjunction with a manned Tug.

SPACE TUG MISSION FREQUENCY CONSIDERATIONS



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SPACE TUG MISSION FREQUENCY CONSIDERATIONS

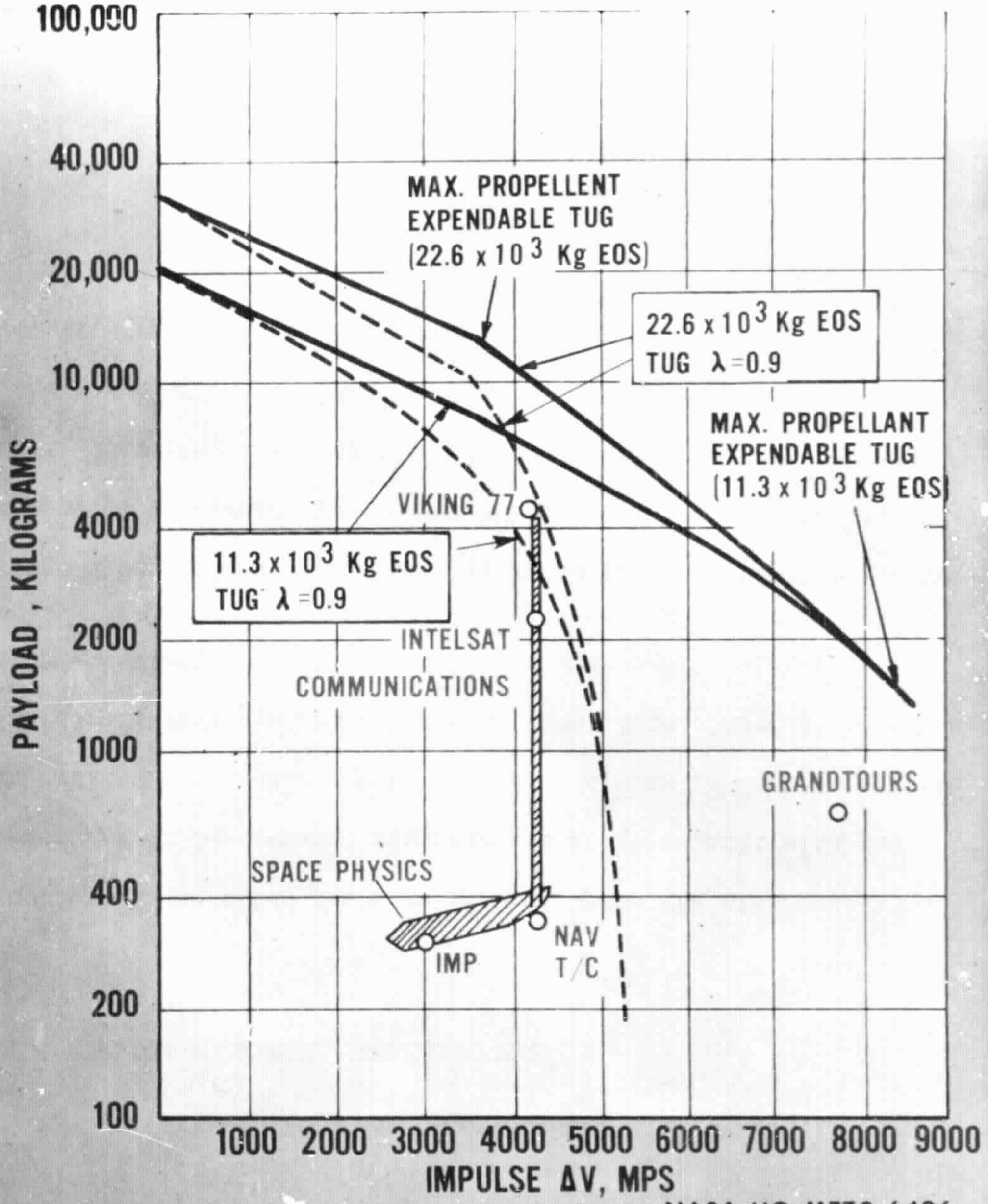
This chart summarizes the estimated use rates for a variety of Space Tug missions. The anticipated usage at the lower end of performance requirements is associated with the use of the Tug in low earth orbit and in lunar orbit. The second peak is associated with use of the Tug to inject spacecraft into synchronous orbit. Satellite placement covers a very broad range because of the variety of desired orbits and spacecraft weights.

A multi-purpose Space Tug should be capable of efficiently satisfying the smaller requirements while still being capable of performing the larger requirements satisfactorily. Studies are currently underway comparing the possible development of a number of special purpose vehicles covering the range of requirements against multi-purpose vehicle concepts that have the capability of less optimally covering the entire spectrum of missions.

Δ V REQUIREMENT FOR TYPICAL PAYLOADS FROM 185 KM , 28.5 DEGREE REFERENCE ORBIT

CAPABILITY OF EXPENDABLE TUG TO PLACE TYPICAL PAYLOADS (SOLID LINE)

CAPABILITY OF RECOVERABLE TUG TO PLACE TYPICAL PAYLOADS (BROKEN LINE)



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ΔV REQUIREMENTS FOR TYPICAL PAYLOADS

FROM 185 KM, 28.5 DEGREE REFERENCE ORBIT

This chart indicates the relationship between Space Shuttle capability, associated Tug performance, and two modes of Tug operation for satellite injection.

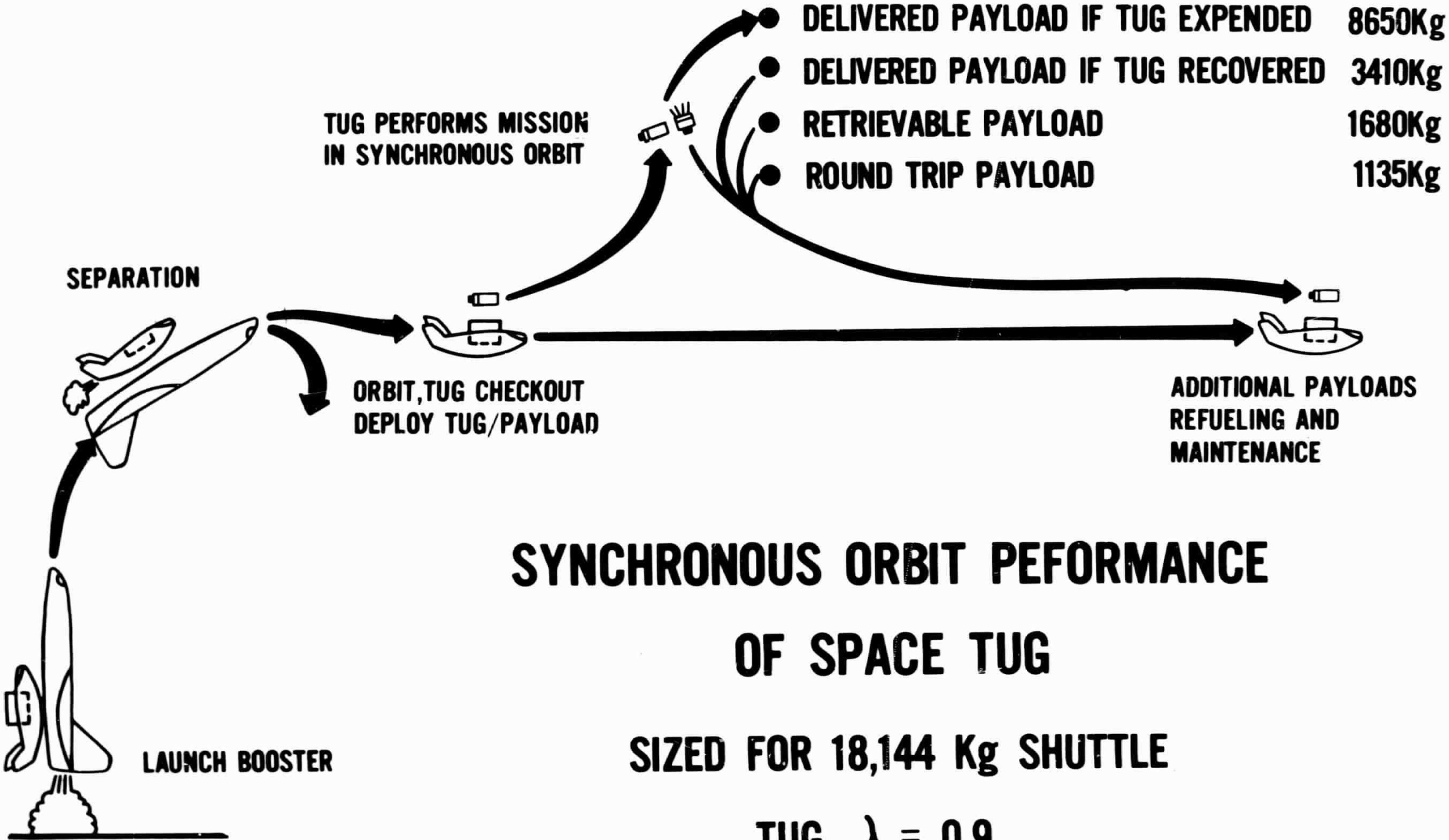
A number of representative satellites are plotted as a function of weight and ΔV requirement. The grouping of satellites of approximately 4300 meters per second is associated with synchronous missions.

It can be seen that a Tug, sized to be compatible with a Shuttle capable of carrying more than 11,000 Kg to the reference space station orbit (500 Km, 55°), is capable of injecting a large percent of the currently projected earth orbital spacecraft into their desired orbits in an operational mode which permits the Tug to return to low earth orbit for reuse. Used in an operational mode in which the Tug is not reused, a similarly sized Tug can be used to deliver the total spectrum of currently planned missions.

The data shown are indicative of a highly efficient design ($\lambda \doteq .9$) and a high performance propulsion system (I_{sp} = 460 sec).

<u>Abbreviations Used on Chart</u>

EOS - Earth Orbital Shuttle (Space Shuttle)
IMP - Interplanetary Monitoring Platform
INTELSAT - International Telecommunications Satellite
NAV T/C - Navigation and Traffic Control



SYNCHRONOUS ORBIT PEFORMANCE OF SPACE TUG

SIZED FOR 18,144 Kg SHUTTLE

TUG $\lambda = 0.9$

TUG Isp = 460

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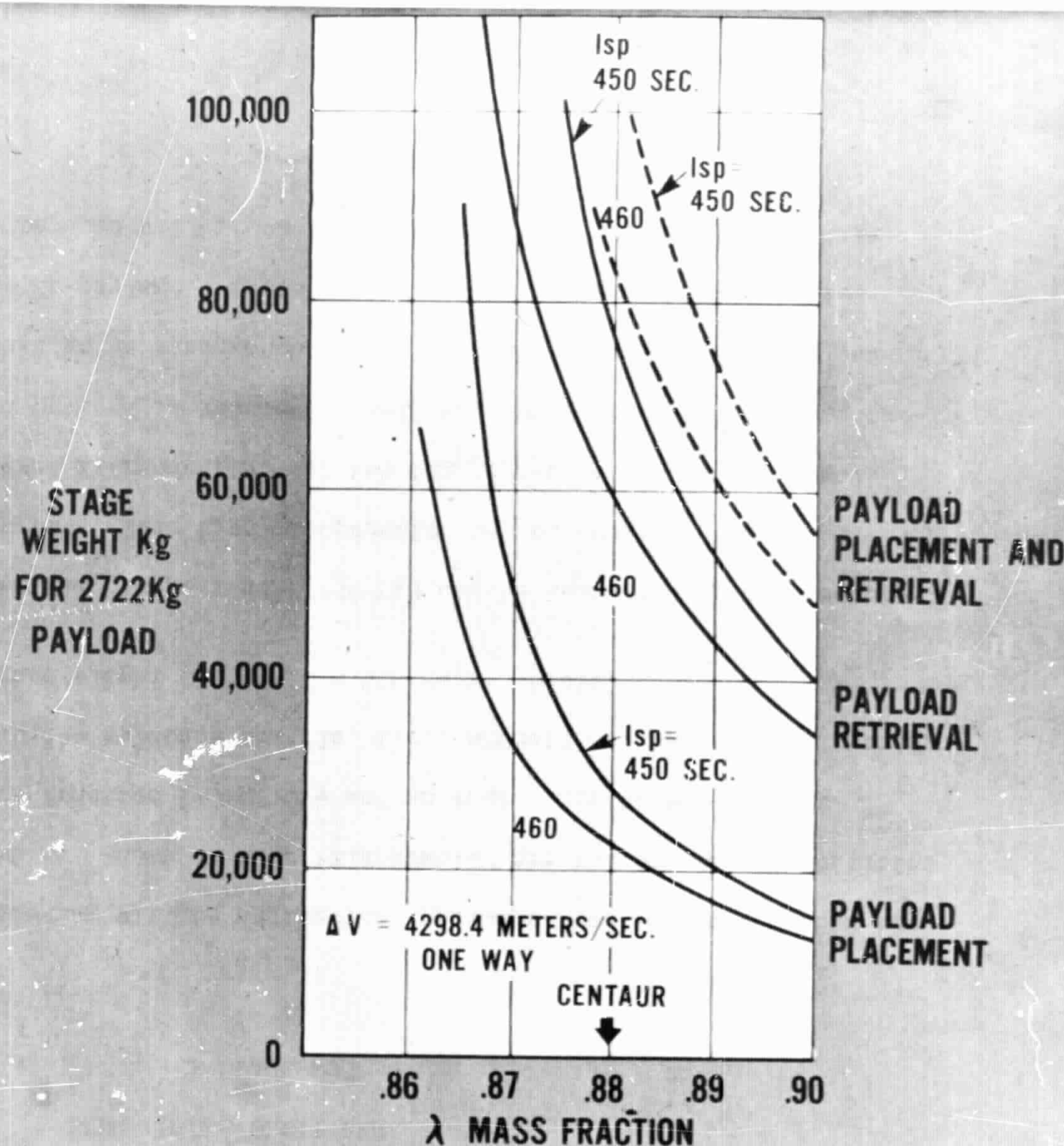
SYNCHRONOUS ORBIT PERFORMANCE

OF SPACE TUG

A key mission for the Space Tug will be delivery of payloads from low earth orbit to synchronous equatorial orbit. Shown in this illustration are the payload capabilities of a Space Tug with a mass fraction (λ) of 0.9 and an engine I_{sp} of 460 seconds. This Tug is sized for a 18,144 Kg Space Shuttle, i.e., a Shuttle capable of delivering 18,144 Kg from Kennedy Space Flight Center to a 500 Km 55° orbit.

If the Tug is expended the largest payload (8650 Kg) can be delivered to synchronous orbit from 185 Km 28.5° orbit. This type of operation may be desirable if large payloads are to be delivered infrequently. If the Tug is recovered, as in normal operations, the delivered payload is reduced to 3419 Kg. Under the assumption shown on the chart, the Tug could go to synchronous orbit and retrieve a 1680 Kg payload or deliver and return a 1135 Kg payload. Probably all of the operational procedures indicated with regard to payload will prove to be desirable at one time or another.

SYNCHRONOUS EQUATORIAL MISSION INERT WEIGHT AND SPECIFIC IMPULSE SENSITIVITY



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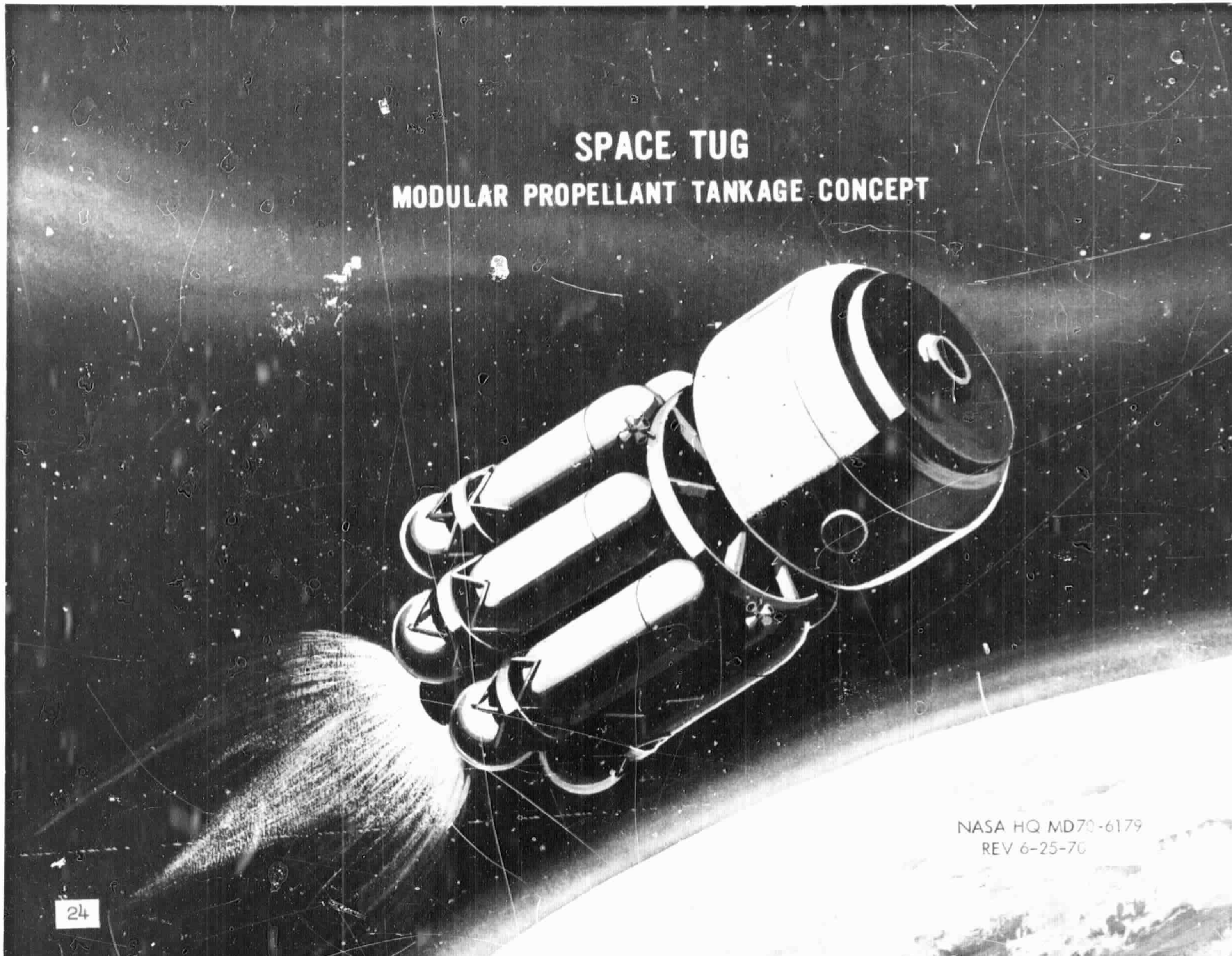
SYNCHRONOUS EQUATORIAL MISSION

INERT WEIGHT AND SPECIFIC IMPULSE SENSITIVITY

Space Tug performance for round trip missions to synchronous orbit is highly sensitive to propellant fraction (ratio of propellant to stage weight), λ, and Specific Impulse (I_{sp}). The adjacent graph shows stage weight for representative values of these parameters for payload placement, retrieval, and round trip. The nature of this sensitivity, particularly for retrieval and round trip missions, illustrates the significance of both high structural efficiency and high engine performance.


SPACE TUG
MODULAR PROPELLANT TANKAGE CONCEPT
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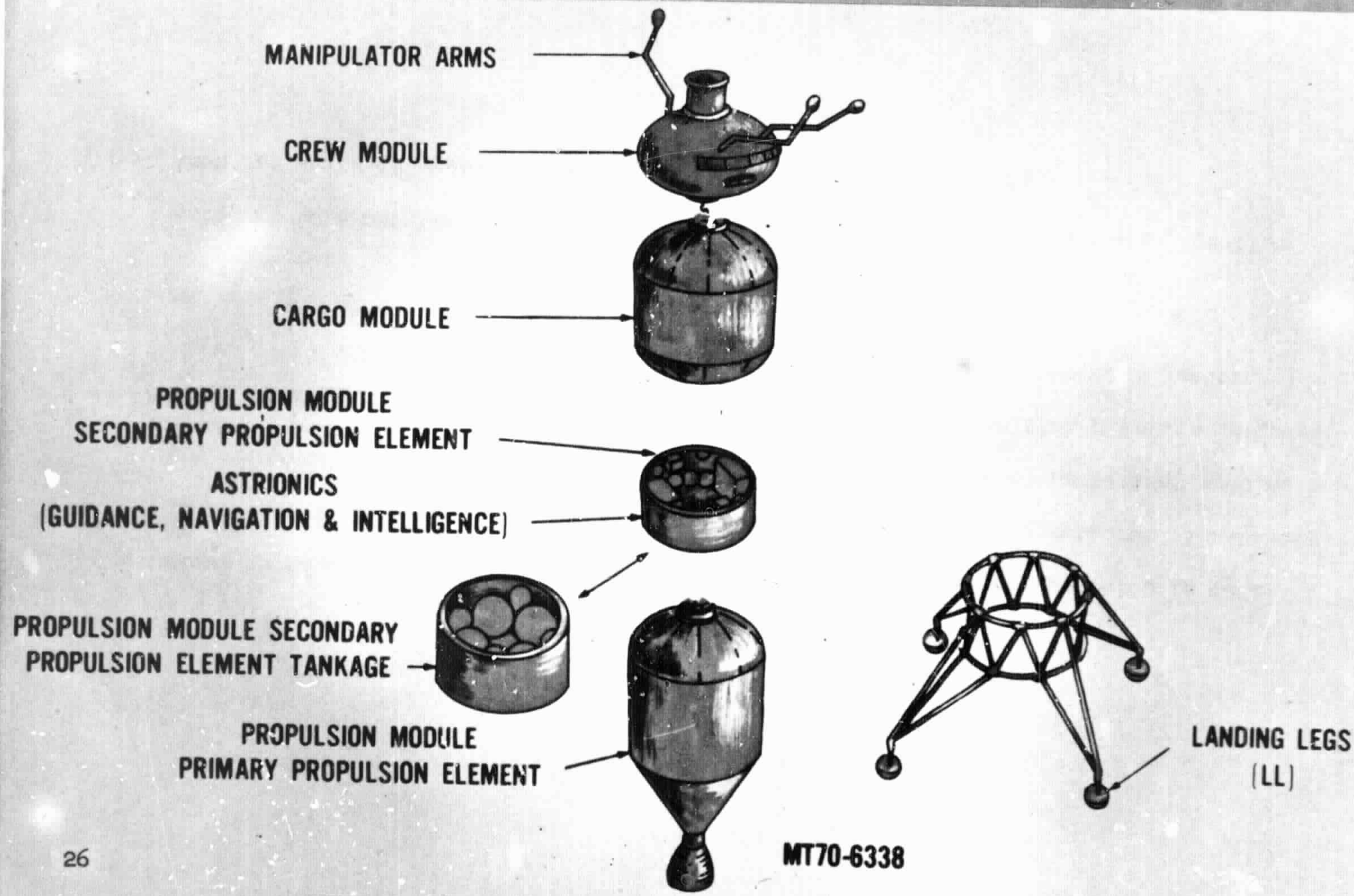
SPACE TUG

MODULAR PROPELLANT TANKAGE CONCEPT

Shown on this chart is an artist's rendition of a tug configuration which is made up of individual propellant modules and thus provides extreme operational flexibility. The stage is designed to be compatible with a variable number of propellant modules which contain oxidizer, fuel and pressurants. The basic propulsion platform includes engines, controls, avionics and primary structure. In concept, the configuration has the option of staging tanks for extremely high performance.

Although this modular concept is extremely versatile, it has a lower mass fraction than one which is designed for a single performance capability.

SPACE TUG
MODULAR TUG ELEMENTS



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SPACE TUG

MODULAR TUG ELEMENTS

The illustration on the adjacent page portrays the various elements which may potentially be required to support the full spectrum of Space Tug applications.

The basic propulsion module, consisting of tankage, engine and pressurants, can be augmented by secondary propulsion tankage. Electronics are contained in an integrated module. A cargo module can be added for applications involving logistic transport of bulk cargo. For manned utilization, a crew module with provision for manipulator arms can be employed. Legs can be added when the Tug is utilized for lunar landing missions.

MULTIPLE STAGES APPROACH

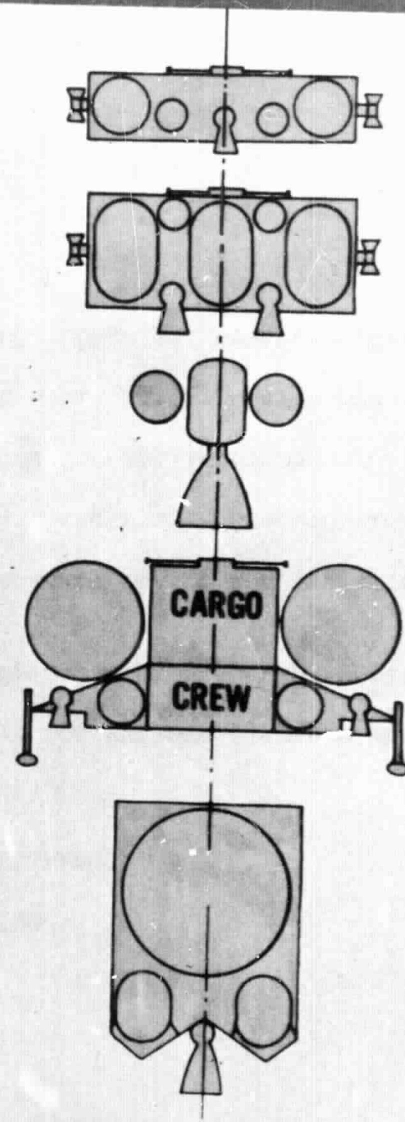
ORBITAL MANEUVERING TUG

ORBITAL TRANSFER STAGE

PLANETARY KICK STAGE

LUNAR ORBIT TO SURFACE SHUTTLE

REUSABLE HIGH ENERGY STAGE



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MULTIPLE STAGES APPROACH

This third alternative to satisfaction of the diversified spectrum of mission requirements shows various stage configurations, each of which is optimized around a specific set of requirements.

This approach yields maximum performance but it is also associated with high cost. Current studies will identify the relative cost and performance factors associated with the several possible system approaches considered.

We hope to achieve a single total system that performs all or nearly all of the required missions without too large an overall penalty. This will prove to be a challenge as indicated by the following table of estimated total impulses for each of the mission optimized stages shown on the chart.

Orbital Maneuvering Stage	$1.36 \times 10^5 - 2.72 \times 10^5$ Kg sec
Orbital Transfer Stage	$2.09 \times 10^6 - 4.17 \times 10^6$ Kg sec
Planetary Kick Stage	$1.27 \times 10^6 - 2.13 \times 10^6$ Kg sec
Lunar Orbit to Surface Shuttle	$8.35 \times 10^6 - 16.7 \times 10^6$ Kg sec
Reusable High Energy Stage	$8.35 \times 10^6 - 16.7 \times 10^6$ Kg sec

Although the last two stages have the same estimated total impulse, their operational requirements impose significant structural and other system differences as indicated by the illustration.

SPACE TUG
DESIRED PROPULSION SYSTEM CHARACTERISTICS

• PERFORMANCE	
THRUST	0.45×10^4 TO 1.36×10^4 Kg
ISP	460 PLUS SEC
THROTTLING	CONTINUOUS 10 TO 1
STEP THRUST (IDLE MODE)	TO 136 Kg
• OPERATIONAL	
RESTARTS PER MISSION	4 TO 20
TOTAL STARTS (LIFETIME)	1,000
BURNTIME	1,000 SEC/MISSION UP TO 100,000 SEC/LIFE
CHILLDOWN	NOT DESIRABLE
MINIMUM TIME BETWEEN STARTS	SECONDS TO MINUTES
GIMBAL ANGLE	UP TO 7 DEGREES
PRESSURIZATION	GASEOUS PROPELLANTS
• MAINTENANCE	
SINGLE MISSION DURATION	UP TO 30 DAYS ACTIVE UP TO 180 DAYS QUIESCENT
REPAIR AND REFURBISHMENT	IN SPACE
OPERATIONAL LIFE	3 PLUS YEARS

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SPACE TUG

DESIRED PROPULSION SYSTEM CHARACTERISTICS

In order to perform the variety of missions previously mentioned, a flexible and versatile propulsion system is required. An estimate of the desired characteristics for the O_2/H_2 main engine(s) are shown in this table. Lunar landings may require multiple engines for increased thrust and mission safety. From a performance standpoint the requirements are within the state-of-the-art except possibly for the desired I_{sp} of greater than 460 seconds. On the other hand, the capability to satisfy the operational requirements imposed on the propulsion system by such things as reuse, inspace maintenance and long life has not yet been demonstrated.

SPACE TUG SCHEDULING

- FOR MAXIMUM UTILIZATION OF THE SPACE SHUTTLE, THE SPACE TUG SHOULD BE DEVELOPED IN THE SAME TIME FRAME AS THE SHUTTLE

- KITS AND SYSTEM REQUIREMENTS FOR LUNAR AND PLANETARY MISSIONS SHOULD BE INTRODUCED AT APPROPRIATE DATES

SPACE TUG SCHEDULING

The Space Tug and Space Shuttle schedules and programs are intimately related. Much of the technology required by the Tug will be developed by the Space Shuttle. For example both use O_2/H_2 main propulsion and will both probably use O_2/H_2 auxiliary propulsion. Many of the proposed missions for the Space Shuttle are dependent upon a Tug type system.

The Space Shuttle is currently planned to have an initial operational capability (IOC) in late 1977 with the basic Space Tug IOC one or two years later. In its first applications the Tug will be unmanned and primarily for earth orbital operations. Mission kits, crew module and system requirements for lunar and planetary missions will be introduced later at appropriate dates.

SPACE TUG
STUDY EFFORTS

- AEROSPACE CORPORATION
- NASA IN-HOUSE
- NASA CONTRACTUAL EFFORT
- ELDO CONTRACTUAL EFFORT

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SPACE TUG

STUDY EFFORTS

This chart lists the current Space Tug study efforts.

The Aerospace Corporation Tug study is one task of the "Joint Air Force and NASA Manned Space Flight Studies" from November 1969 through June 1970. The Tug task covered mission and operational requirements, conceptual designs (single and multi-purpose systems), technology requirements and costs.

NASA In-house studies have been preliminary and relate to mission requirements, analyses, conceptual design analyses, program integration and preparation of the statement of work for the contractual effort. The results of the in-house work is summarized in this presentation.

The NASA Contractual Effort "Analysis of a Reusable Space Tug," is a 9 month pre-phase A study which was awarded to North American Rockwell Corporation in June 1970 (Contract NAS9-10925). The study is being conducted through the Manned Spacecraft Center at Houston, Texas with support from Marshall Space Flight Center, Huntsville, Alabama. The objectives of the study are covered on the next chart.

It is our understanding that the ELDO contractual efforts will be initiated in the near future and will continue for approximately 6 months. The study will cover Requirements and Vehicle System studies and a Propulsion System study. As the NASA and ELDO studies progress we will welcome the continued exchange of information which has already been initiated.

SPACE TUG CONTRACTUAL STUDY
"ANALYSIS OF A REUSABLE SPACE TUG"
OBJECTIVES

- **PRIMARY:**
  - DETERMINE MISSION REQUIREMENTS, OPERATIONAL MODES, MISSION AND HARDWARE INTERFACES, SYSTEM REQUIREMENTS AND TECHNOLOGY IMPLICATIONS
  - DETERMINE FEASIBILITY OF SINGLE TUG SYSTEM TO PROVIDE LOGISTICS SUPPORT FOR MISSIONS OF INTEREST
- **OTHER:**
  - VEHICLE AND SUBSYSTEM CANDIDATES THROUGH MISSION, OPERATIONS AND DESIGN TRADE STUDIES
  - FOR EACH MISSION AREA, IDENTIFY IMPACT OF MULTI-PURPOSE SPACE TUG SYSTEM
  - CAPABILITIES AND LIMITATIONS OF CONCEPTUAL DESIGN, TO SUPPORT PROPOSED MISSIONS
  - PREPARATION FOR PHASE A STUDY

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SPACE TUG CONTRACTUAL STUDY

"ANALYSIS OF A REUSABLE SPACE TUG"

OBJECTIVES

The objectives of the pre-phase A study are shown here. It is noted that emphasis is on mission requirements, operational modes and hardware interfaces, system requirements and technology implications, plus the feasibility of a single Tug to adequately support missions of interest, rather than on specific designs. Follow-on Phase A studies will emphasize preliminary design aspects of the Tug system and the associated development program.

SUMMARY

- THE SPACE TUG HAS A LARGE NUMBER OF MISSION APPLICATIONS
- THE WIDE RANGE OF SPACE TUG ENERGY REQUIREMENTS NECESSITATES A VERSATILE DESIGN CONCEPT
- FOR MANY APPLICATIONS, THE SPACE TUG MUST BE OF HIGHLY EFFICIENT STRUCTURAL DESIGN AND HAVE HIGH ENGINE PERFORMANCE
- CURRENT EFFORT IS DIRECTED TOWARD ESTABLISHMENT OF FIRM SYSTEM REQUIREMENTS AND DESIGN CONCEPTS

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